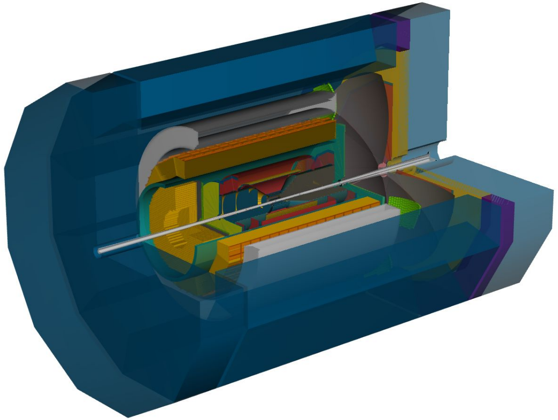
ATHENA Bi-weekly Meeting

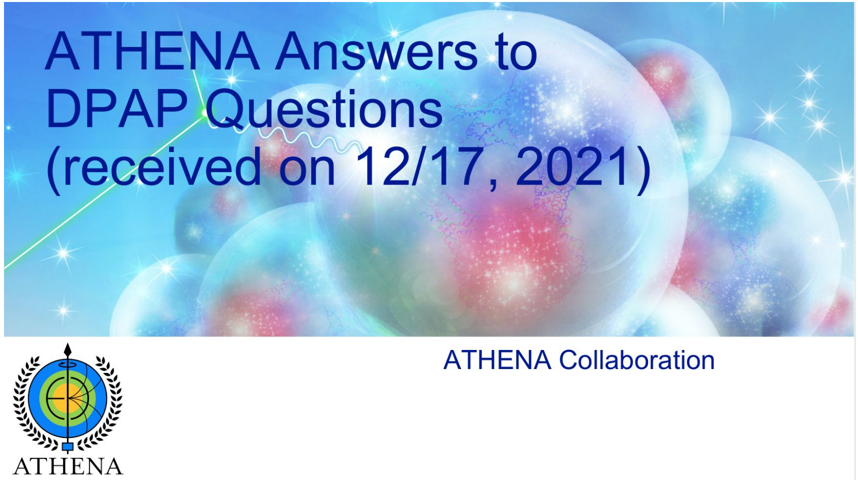
Highlights of homework answers: Detectors



Maria Żurek
Argonne National Laboratory

03/02/2022

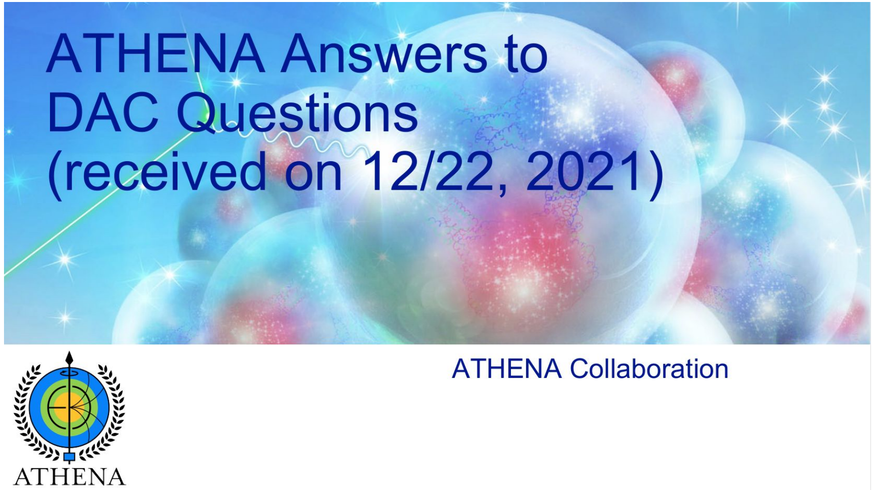
Questions related to detector issues



ATHENA Answers to DPAP Questions (received on 12/17, 2021)

ATHENA Collaboration

ATHENA



ATHENA Answers to DAC Questions (received on 12/22, 2021)

ATHENA Collaboration

ATHENA

Questions related to detector issues

From DPAP:
T-1, T-2, T-3, T-4, T-5, T-6, **G-5, G-6, G-7**

T - Technical Aspects
G - General Physics Performance

From Detector Advisory Committee (DAC):
TR1, TR2, TR3, **CA1, CA2**

TR - Tracking
CA - Calorimetry

DAC Questions - Tracking

TR1 The proposed silicon tracker is based on the **65 nm MAPS** technology currently under development at ALICE. What are the impacts on the silicon tracker design and its physics performance **if ALICE has to fall back on 180 nm technology**?

TR2 Based on knowledge and operational experience from currently installed/operating silicon-based systems, estimate the **number (or fraction) of dead channels** to be expected in your proposed tracker (as function of time, if possible). Estimate the **impact** of this typical number of dead pixels/sectors **on physics results**. What fraction of the MAPS units will be active (versus passive balconies)?

TR3 The µRWell foils are a more recent technology; large installations on a 1m scale are proposed for ATHENA. Does there exist **experience with long-term operation of such large trackers.**

DAC Questions - Calorimetry

CA1 The barrel ECAL is an innovative detector and will add some additional integration requirements and risk.

- What are the **physics impacts** of the proposed design relative to a more simple design without the imaging layers?
- Could you describe in more detail the **role of the different groups** in the design, construction, commissioning, electronics, etc for this detector?

CA2 What is the **area of AstroPix detectors** that are needed for the barrel; is this large relative to previous production sizes for this technology?

Technical Questions

T-1 Provide some details on how **detector calibration** will be done

T-2 Can the **physics performance** be **optimized by adjusting the field strength** of the spectrometer magnet to the beam energies of different runs?

T-3 What happens to the physics performance **if AC-LGADs have to be replaced by something else** (e.g. LGADs)?

T-4 (i) What happens to the physics performance **if C2F6 and C4F10 cannot be used**? (ii) Have you considered using alternative gases for the initial design rather than as a later modification?

T-5 What happens to the physics performance **if** you need to use **lead glass instead of SciGlass**?

T-6 How will **radiation damage** of detector components affect physics performance, including forward and backward instrumentation? Please provide a map of the radiation field in the detector.

General Physics Performance Questions

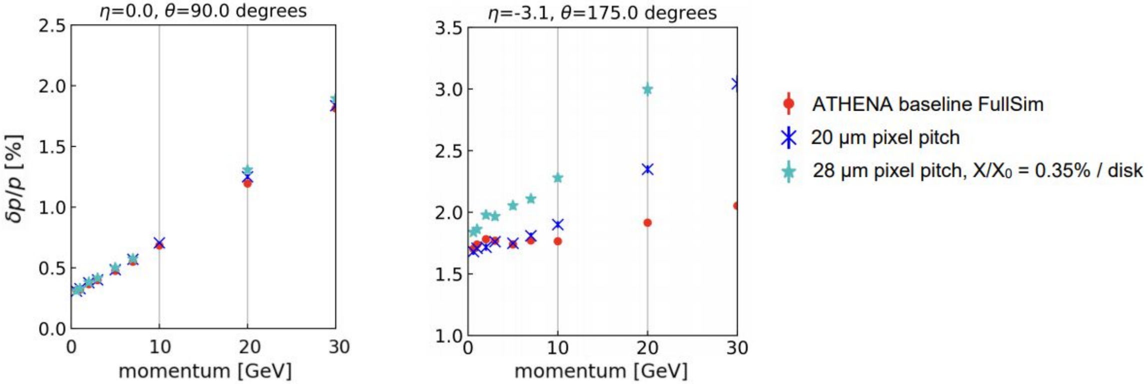
G-5 Provide estimates of the **pi/mu rejection** factor in different regions of pseudorapidity
G-6 Provide some detail on how you estimate the accuracy of the **luminosity measurement**
G-7 Provide some details about the acceptance and resolution in Q^2 and energy for **electrons scattered at very low angles**

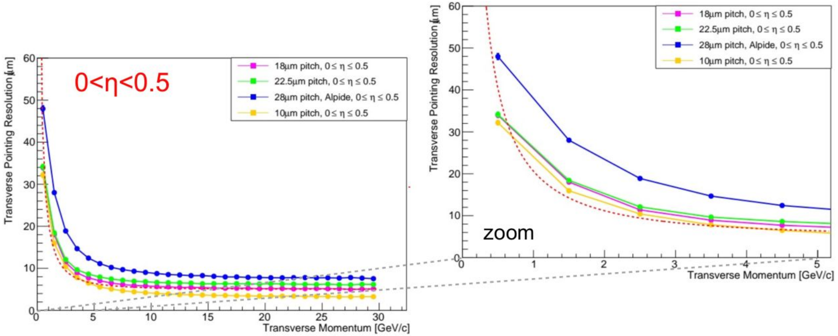
Tracking (DAC)

TR1 The proposed silicon tracker is based on the **65 nm MAPS** technology currently under development at ALICE. What are the impacts on the silicon tracker design and its physics performance **if ALICE has to fall back on 180 nm technology**?

Tracking (DAC)

The impact(s) on **tracking** and **vertexing** capability from the increased pixel size and additional material of the proposed fall-back solutions have been studied in ATHENA full simulations:





10, 18, and 22.5µm pixel pitch results for stitched sensors and curved silicon with X/X_0=0.05% per vertex layer

28µm pixel pitch, 180nm technology, has X/X_0=0.3% per layer

Tracking

- Fallback solutions can **meet mid-central rapidity** tracking resolution requirements
- **Degraded momentum resolution at shallow angles**, in the electron going direction because of material budget and pixel pitch.

Vertexing

- **Minimized material in the vertexing layers crucial** to achieve the vertexing requirements
- Increased pixel pitch associated with fallback solutions has a smaller effect.

Tracking (DAC)

- The fallback option for the ALICE ITS-3 sensor — should the 65 nm stitched Tower process prove to be unsuitable — is a **180 nm Tower process sensor with similar but probably not identical specifications**. Moving to the 180 nm process would probably involve moderately **increasing the pixel pitch and a moderate increase in the power dissipation**.

- The current design goals for the ITS-3 in **65 nm technology includes a pixel size of 10 μm2** and a **power dissipation of 20 mW/cm2**. ATHENA simulations include services (conductor material) corresponding to this power dissipation. We have been conservative in the simulations: the single point resolution used only includes the geometric component of the pixel pitch. If one would fit the hit clusters, one can improve the single point resolution by typically 50%. While we believe it is probable that a single point resolution based on a 180 nm fallback sensor would fall within this margin, we have repeated our simulations with representative variations of pixel size and material budget.

DAC Questions - Tracking

TR2 Based on knowledge and operational experience from currently installed/operating silicon-based systems, estimate the **number (or fraction) of dead channels** to be expected in your proposed tracker (as function of time, if possible). Estimate the **impact** of this typical number of dead pixels/sectors **on physics results**. What fraction of the MAPS units will be active (versus passive balconies)?

Tracking (DAC)

1st MAPS-Detector operated in collider experiment STAR HFT: 5% of the pixels and one single damaged sensor (Au-Au 2016 Run) no impact other than the **loss of 5% of the acceptance**

- **Latch-up based damage** to the AMS 0.65 µm process sensors
- **Mimosa - chip significantly less radiation hard** then new MAPS-chips
- Not representative of what can be expected: **this type of issue has been addressed** in the design phase of ALPIDE (ALICE ITS) will be propagated to the new 65 nm Design

2nd MAPS-Detector to be operated : ALICE ITS upgrade - the ALPIDE Tower 180nm based sensors

- The installed ITS upgrade detector has a **very high fraction of live pixels**
- **Extensive beam running over next years** (any issues expected to be addressed in the ITS-3 sensor)
- Based on extensive testing of ALPIDE: **sensors should maintain their full existing live over 10 years** of running at the LHC
- For the EIC use, **we expect damage from radiation to be negligible** (the dose rates are at least a factor of 100 below)

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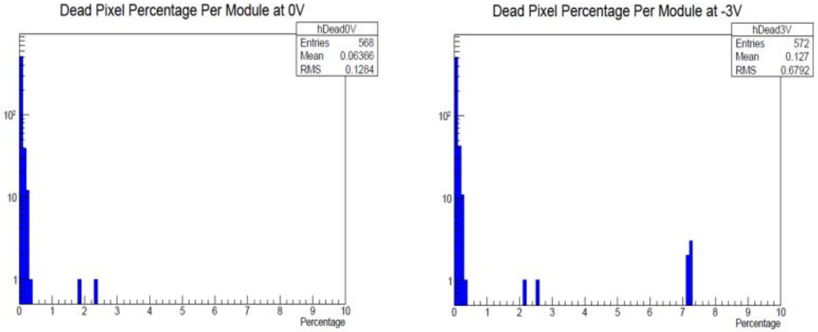
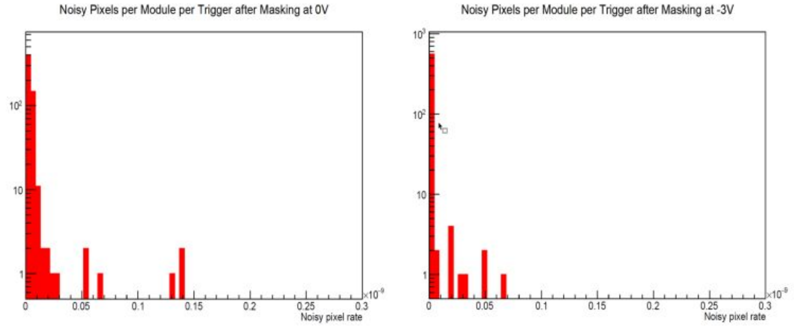


Fraction of dead pixels per module at 0 and -3V back bias



Noise rate in modules, composed of 14 sensors with ~0.5 M pixels each. All modules used in 68 delivered staves are included in the plot

With this number of life pixels, no impact on the tracking and vertexing performance is expected

DPAP Question - Radiation Damage

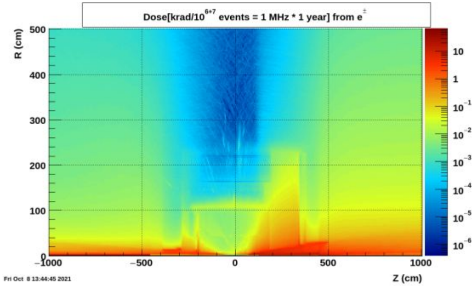
T-6 How will **radiation damage** of detector components affect physics performance, including forward and backward instrumentation? Please provide a map of the radiation field in the detector.

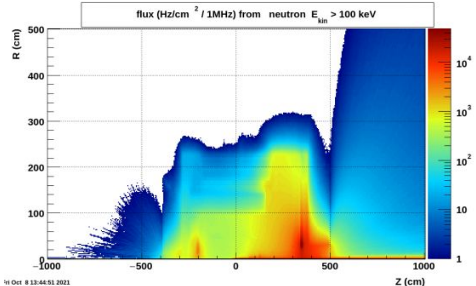
Radiation Damage (DPAP)

- **All sources of beam backgrounds** (synchrotron radiation, electron and hadron beam gas) and radiation (neutron and ionizing radiation) have been **simulated** and documented in detail at https://wiki.bnl.gov/athena/index.php/Beam_backgrounds
- The radiation level at EIC is at least a factor O(100) reduced compared to the LHC

- **Example: Radiation map in the detector caused by primary interactions**
  - ➢ Pythia 6 simulation tuned for HERA experiments, COMPASS and STAR
  - ➢ Compared against CMS HL-LHC projections

ATHENA



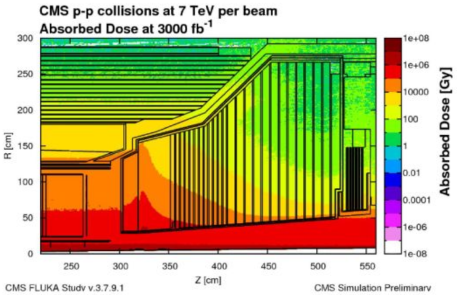


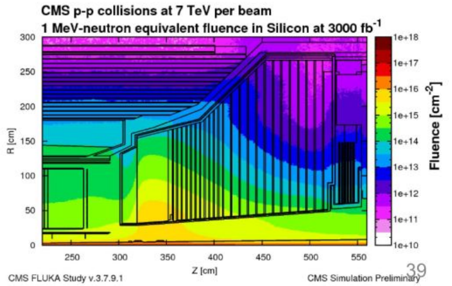
- **Dose from secondary e+e- particles**
  - <10 kRad / year in ATHENA …
  - … compared to dozens of MRad @ CMS

- Min. bias DIS event rate is ~500 kHz at 10^{34} cm^{-2}s^{-1} luminosity
- A year of EIC running is ~2*10^7 s

- **Neutron fluence**
  - At most ~10^{11} cm^{-2} annually in ATHENA …
  - … compared to 10^{15} cm^{-2} and more @ CMS

CMS





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Impact of Imaging Layers in Barrel ECAL

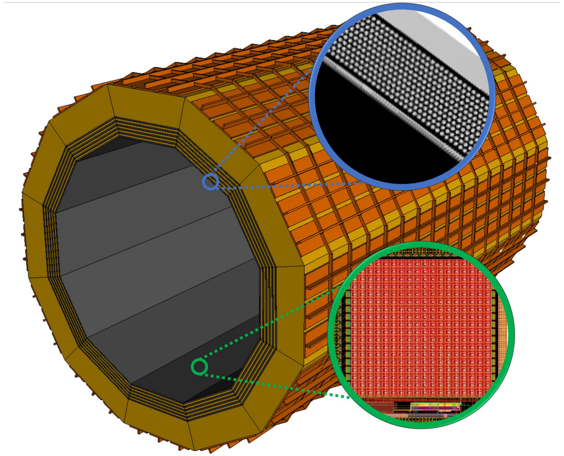
Excellent position resolution allowing precise 3D shower imaging

Significantly improved **electron/pion separation** with respect to E/p method

- Impact on DIS cross section and asymmetries

Separation of ɣs from π^0 decays at high momenta up to ~40 GeV/c. Precise position reconstruction of **ɣs** (below 1 mm at 5 GeV).

- Impact on DVCS and photon physics



Tagging **final state radiative photons** from nuclear/nucleon elastic scattering at low x to **benchmark QED internal corrections**

Imaging layers provide:

- precise measurement of photon coordinates and the angle between electron and photon

Allowing PID of **low energy muons** that curl inside the barrel ECal (< 1.5 GeV with 3T MF)

- Impact on J/psi reconstruction, TCS

Provides a **space coordinate for DIRC** reconstruction (no need for additional large-radius tracking detector)

- Improving PID for SIDIS and beyond
- Improved tracking resolution for high-momentum particles

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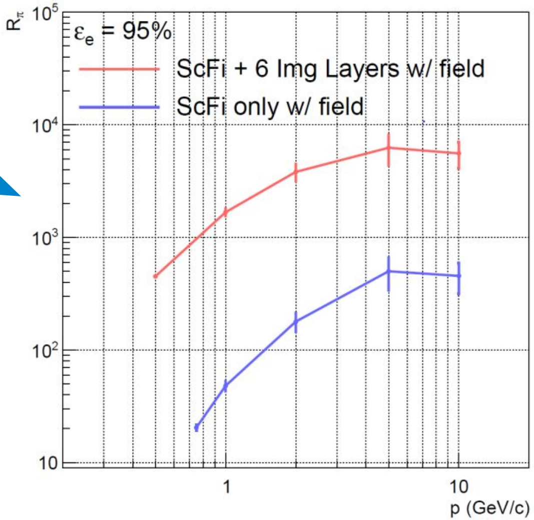

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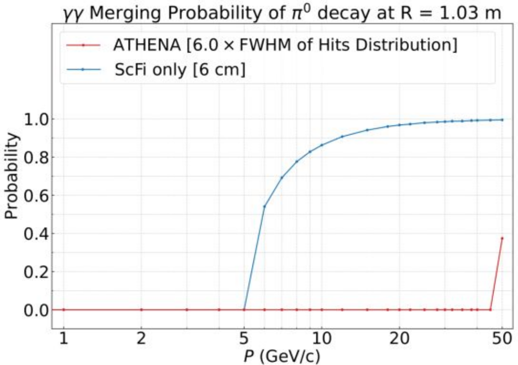

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Spatial resolution of ɣ

- Imaging layers: order **of ~1 mm** (1 GeV ɣ)
- GlueX ScFi: of the **order of centimeters** from timing resolution (~150 ps for 1 GeV ɣ)

Allowing PID of **low energy muons** that curl inside the barrel ECal (< 1.5 GeV with 3T MF)

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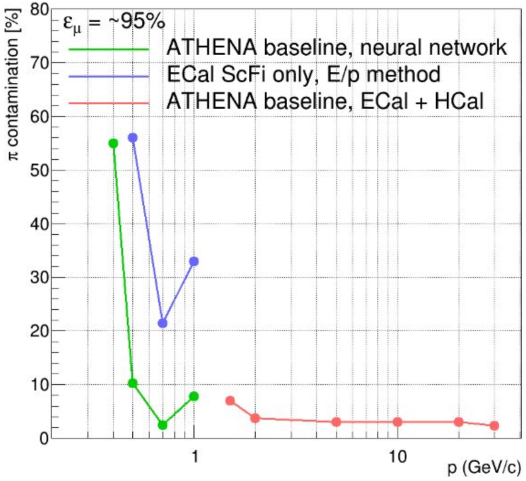
DPAP Question - muon PID

G-5 Provide estimates of the **pi/mu rejection** factor in different regions of pseudorapidity

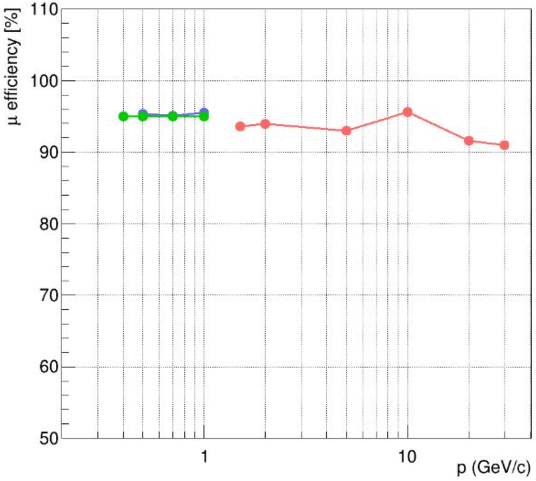
Muons in the Barrel region

- Muon/pion separation in **central region** determined from information from the **Barrel ECal** and **HCal**
- Results for single particle simulation, **see details in the following slides**

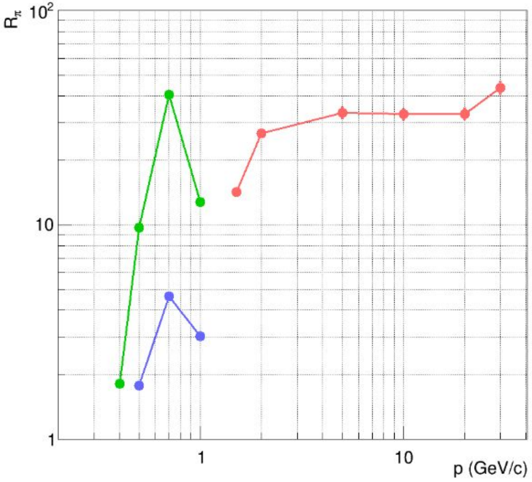
π contamination



μ efficiency



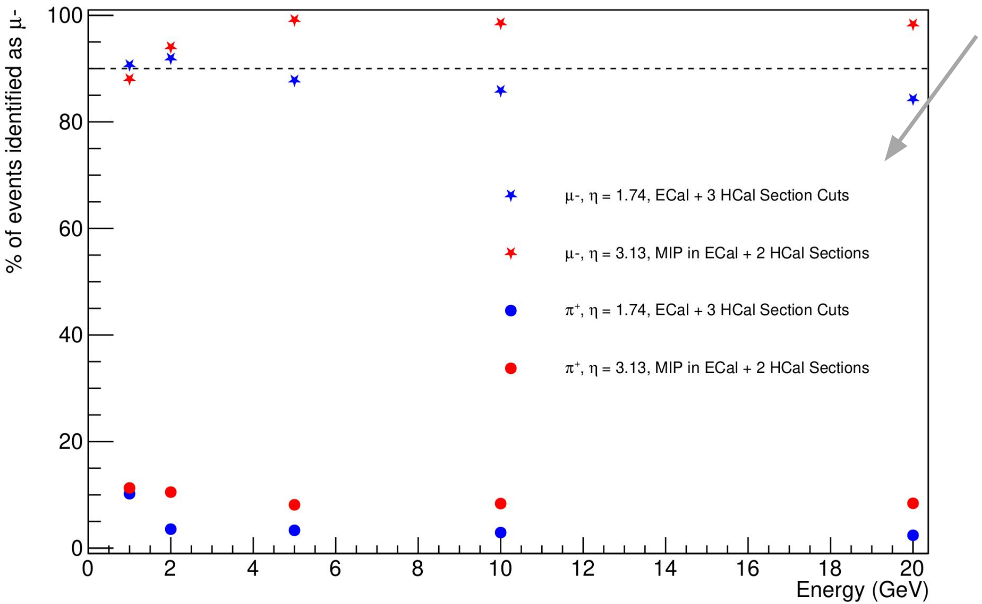
π suppression



- **At η = 0: muons >~1.5 GeV/c reach HCal, and <~1.5 GeV/c curl inside the BCal** (different approach to analysis)
  - ➢ This discontinuity (in reaching HCal) is rapidity dependent
- Neural Network studies in ECal done for η = (-1,1), ECal+HCal studies and E/p studies in ECal (see also answer to the **DAC question CA1**) done for η = 0
- Further improvements to muon/pion separation from PID detectors expected (DIRC)

Muons in the Hadron Endcap region

- Muon/pion separation in **forward region** determined from **pECal** and **pHCal** responses
  - ➢ pEndCap calorimeter has five longitudinal segments: pECal + four sections in pHCal, total ~ **7 interaction lengths**



Percent of events identified as muons for generated pion sample (pion contamination, dots) and muon sample (muon efficiency, stars) at η=1.74 and η=3.13

For **~90% muon efficiency**, only **a few % of pions are misidentified as muons**

Simulation:

- Single particle simulation at η=1.74 and η=3.13 with stand-alone pHCal and pECal

Selection Criteria:

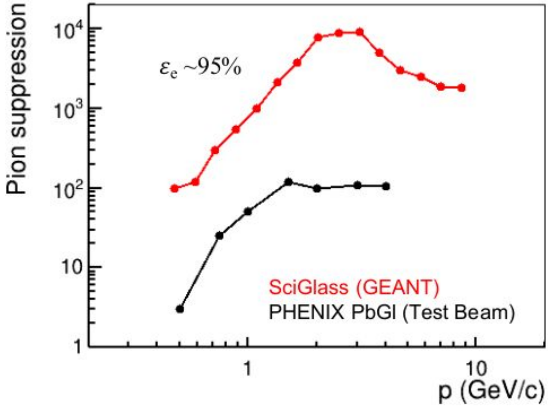
- MIP-like signal in pEndCap calorimeter sections (cut on energy deposit)
- Number of hits along the tracks consistent with no shower (at higher energy/rapidities)

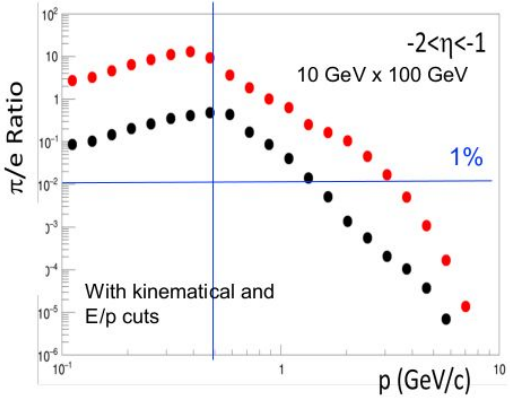
DPAP Question - What if SciGlass ⇢ Lead Glass

T-5 What happens to the physics performance **if** you need to use **lead glass instead of SciGlass**?

DPAP Question - What if SciGlass ⇢ Lead Glass

- The most critical performance goal of the EMCal in this region is **pion suppression for electron identification**.
- **The final π/e ratio** for DIS kinematics reconstruction **is required to be between 1% to 8%**, depending on beam energy (see Table 8.1 of the YR).
- Cutting on E/p for PbGl would result in a π/e ratio of **<1% for p > 3 GeV/c**.
- **The final π/e suppression will be achieved utilizing the Aerogel-based RICH**. It will provide additional pion suppression (>3σ for π/e separation at <2-3 GeV/c) capabilities to keep the final π/e ratio below 1% for p > 0.5 GeV/c.

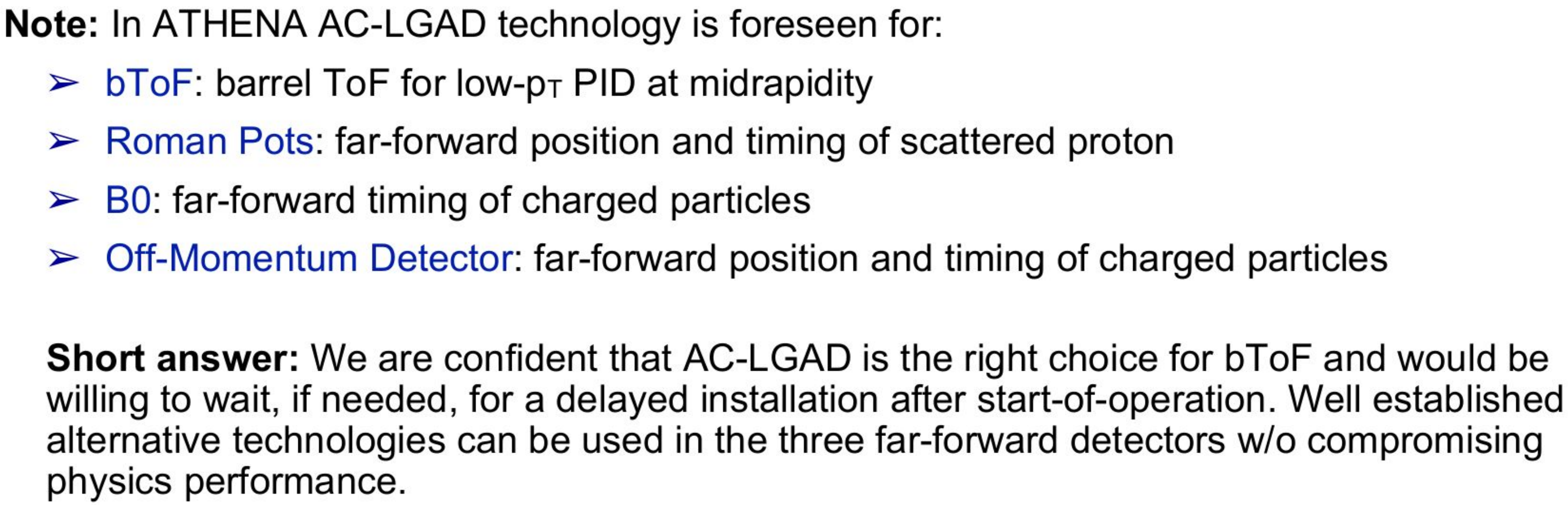




DPAP Question - What if AC-LGADs ⇢ LGADs (e.g.)

T-3 What happens to the physics performance **if AC-LGADs have to be replaced by something else** (e.g. LGADs)?

DPAP Question - What if AC-LGADs ⇢ LGADs (e.g.)



Note: In ATHENA AC-LGAD technology is foreseen for:

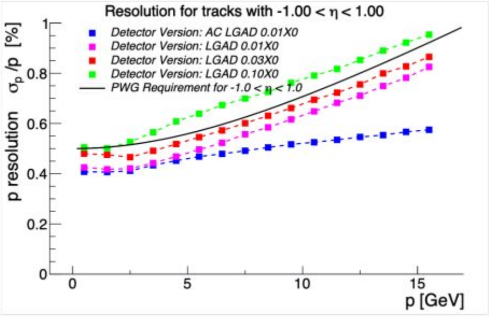
- bToF: barrel ToF for low-p_T PID at midrapidity
- Roman Pots: far-forward position and timing of scattered proton
- B0: far-forward timing of charged particles
- Off-Momentum Detector: far-forward position and timing of charged particles

Short answer: We are confident that AC-LGAD is the right choice for bToF and would be willing to wait, if needed, for a delayed installation after start-of-operation. Well established alternative technologies can be used in the three far-forward detectors w/o compromising physics performance.

- **Roman Pots and OMD:** If AC-LGADs are unavailable: existing MAPS with a suitable timing layer (e.g. DC-LGAD) would satisfy all the requirements
- **B0:** Alternative timing layer using DC-LGADs (strips) using two layers for x & y orientation

Is LGAD an Alternative for bToF?

	AC-LGAD (strip)	LGAD (strip)	LGAD (pixel)	LGAD (ATLAS/CMS)
Channel dimension (mm)	0.5×28	0.5×28	4×4	1.3×1.3
Position resolution (mm)	0.015 in $r \cdot \phi$	0.15 in $r \cdot \phi$	1.2	0.4
Acceptance	0.98	0.88	0.95	0.85
Material per layer (X_0)	~1%	~1%	2-3%	10-15% (not optimized)
Sensor and ASIC R&D	Yes	Yes	Yes	N/A



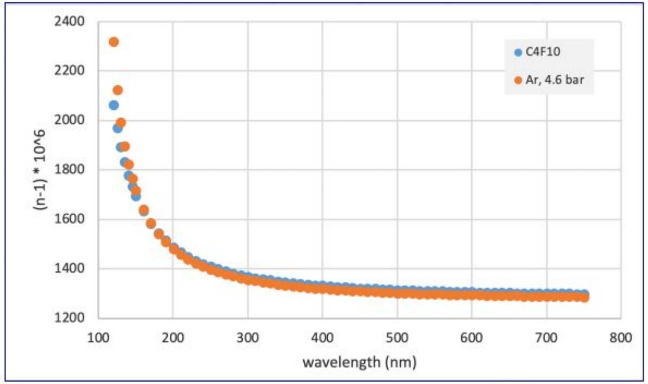
- **No advantage of replacing AC-LGADs by LGADs**
  - ➢ degradation of momentum resolution due to lower spatial resolution (see Fig. above)
  - ➢ additional material degrades bECal performance
    - ✓ excludes LGAD used by ATLAS/CMS since 10-15% X/X_0 not acceptable
  - ➢ smaller acceptance
  - ➢ R&D still needed for all options but ATLAS/CMS LGAD
    - ✓ to achieve optimal design, a similar level of R&D efforts on sensor, ASIC and other components of the detector system would still be needed for LGADs.

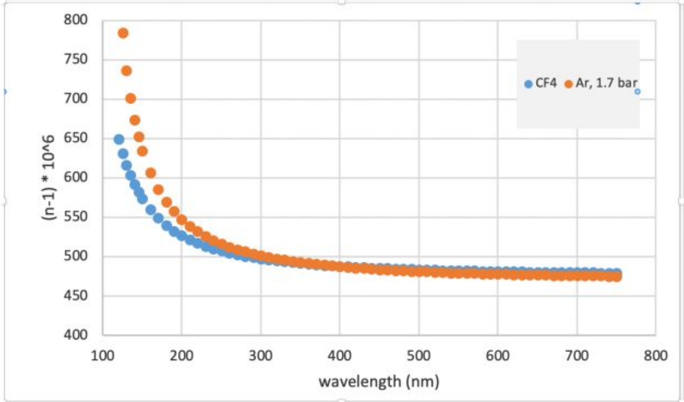
DPAP Question - What if no C2F6 and C4F10

T-4 (i) What happens to the physics performance **if C2F6 and C4F10 cannot be used**? (ii) Have you considered using alternative gases for the initial design rather than as a later modification?

DPAP Question - What if no C2F6 and C4F10

- About (i)
  - **Fluorocarbons** are selected as radiator gasses in gaseous RICHes because of their :
    - ✓ **High density** at room conditions → high Cherenkov photon yield
    - ✓ **Small chromaticity** → good Cherenkov angle resolution
  - These requirements **must** be preserved to ensure ATHENA PID performance. They can be obtained pressurizing Ar at ~ 3 bar.
    - ✓ Contrary to fluorocarbons, Ar does not have green-house issues. It is cheaper, easier to procure, does not require complex gas recycling systems.
- About (ii)
  - **Yes: we are considering pressurized Ar for the initial design**
    - ✓ The challenge is the mechanical design of the vessel, that should guarantee safety operation with limited amount of material
    - ✓ Preliminary studies of this design have started





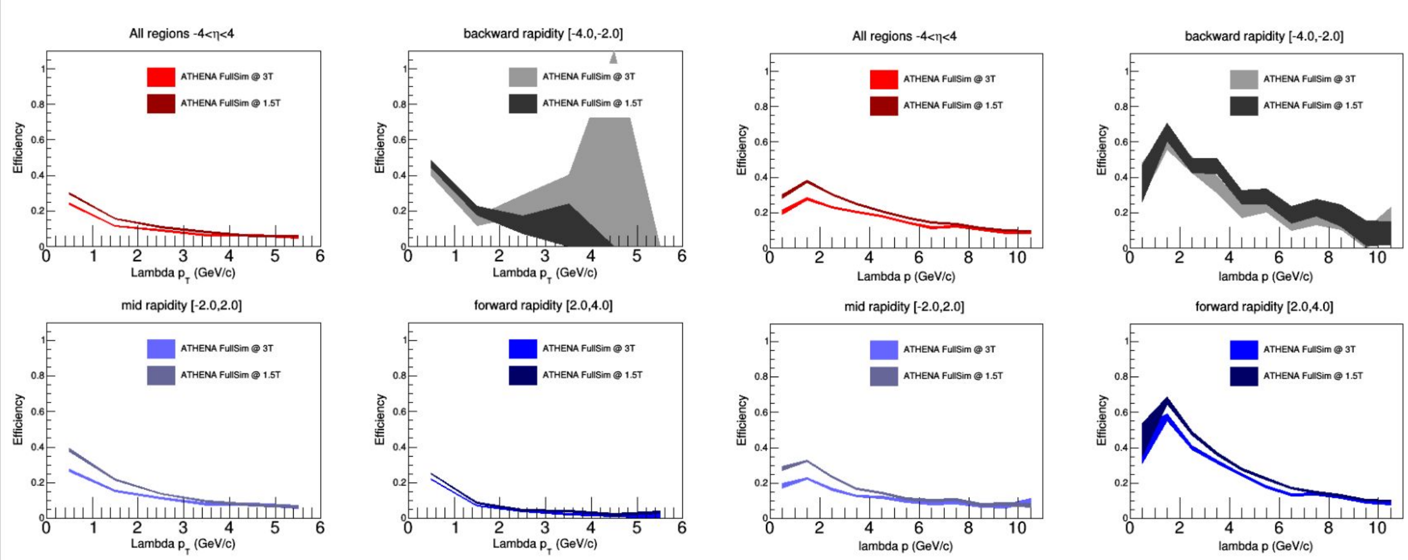
DPAP Question - Impact of lower MF

T-2 Can the **physics performance** be **optimized by adjusting the field strength** of the spectrometer magnet to the beam energies of different runs?

DPAP Question - Impact of lower MF

- **The field can be reduced**: no technical limitation exists to operate the magnet at a lower field at any beam energy, neither from the solenoid, detector nor the accelerator side. However, we consider the **full 3T field the optimal choice for the body of NAS measurements**.
- The main performance impact of reducing the B-field is an i**ncreased acceptance at low p/p_T**, nevertheless at the expense of **losing p/p_T resolution** in combination with a **worse signal to background ratio** (e.g. D0).
- The ultimate decision if low B-field runs are needed at all at different √s will be best based on operational experience.

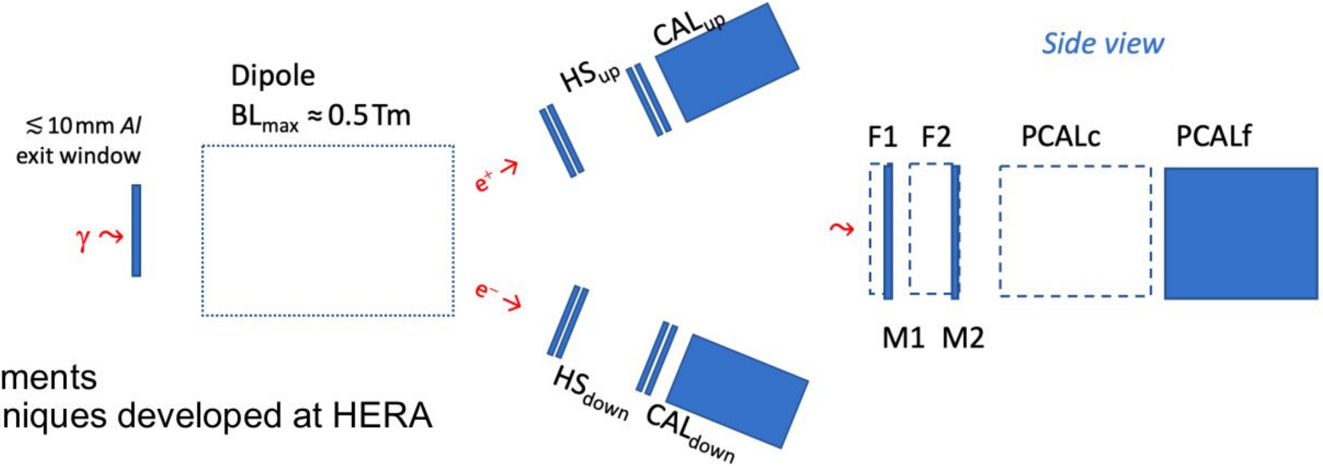
Example:
Impact on λ reconstruction efficiency



DPAP Question - Luminosity measurement

G-6 Provide some detail on how you estimate the accuracy of the **luminosity measurement**

DPAP Question - Luminosity



- ATHENA luminosity measurements are based on **extending** techniques developed at HERA

- **Three complementary methods** will be used for luminosity determination: (a) bremsstrahlung photon counting using (movable) PCALc; (b) counting of photon conversions in exit window using “luminosity spectrometer”; (c) photon energy flow measurement using PCALf (and movable SR filters F1/2 and monitors M1/2). These 3 methods, affected by very different systematic uncertainties, will be cross-calibrated to each other.

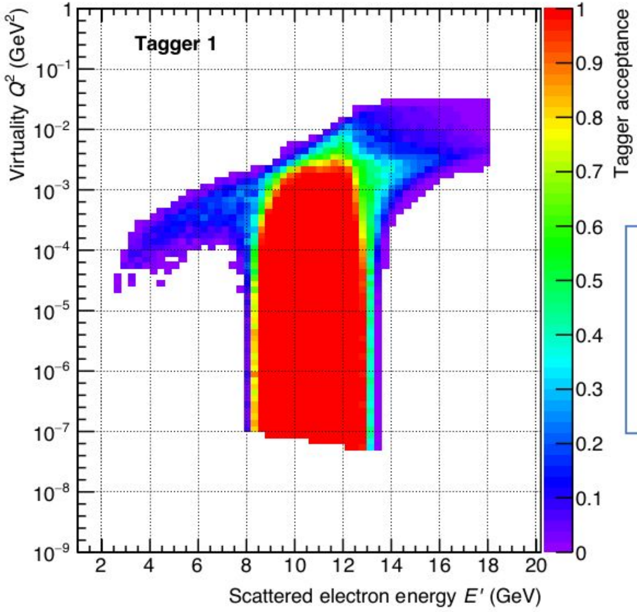
- This will ensure **1% luminosity precision** for all electron beam energies (from 5 to 18 GeV) as well as hadron beam species (from protons to gold nuclei), and for low and high luminosity running at EIC

DPAP Question - Luminosity measurement

G-7 Provide some details about the acceptance and resolution in Q^2 and energy for **electrons scattered at very low angles**

DPAP Question - Electrons at very low angles

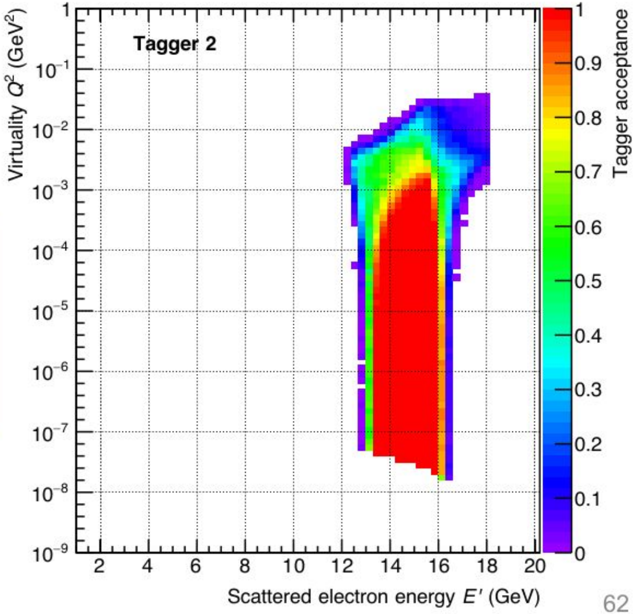
- The acceptance of low-Q^2 taggers in ATHENA is limited by the apertures of the upstream electron beamline elements and by the presence of the dipole magnet B2eR, in front of the taggers. To maximize the electron acceptance and avoid unnecessary complications we propose to install **two electron detectors**, *Tagger 1* at 20 m from IP6 and *Tagger 2* at 37 m, with complementary acceptances, as shown for 18 GeV electrons:



High acceptance, close to 100%, is expected for the region:

$0.9 > y > 0.5$ and $Q^2 < 10^{-3}$ GeV^2,

where inelasticity $y = 1 - E'/E$



Thank you